Transient leakage flux in small universal motors

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Abstract: This communication reports an investigation into the transient back-of-core flux that arises in a small universal motor. A substantial leakage flux has been shown to exist under starting conditions which is caused by excess field ampere turns saturating the core and forcing the flux into the back-of-core region.

1 Introduction

One common assumption in electrical machine theory is that the iron circuit carries the whole of the machine flux, except for the end-winding leakage flux. This is a reasonable assumption for machines running in the steady state, and it certainly simplifies the mathematical analysis. However, it is not necessarily true for all machines at all times and, in particular, it is not true in those machines with a high level of saturation or under transient conditions. Although back-of-core leakage flux is a 2nd-order effect, nevertheless it can under some circumstances be of importance.

Abolins and Rieger [1] have, for instance, demonstrated that in the case of large turbogenerators, up to 40% of the iron loss may be attributed to the frame rather than the core. This is because, at high levels of core flux density, flux starts to leave the core and enter the frame, causing eddy-current losses in the process. Hughes and Miller [2] have derived expressions for back-of-core leakage fields for conventional and superconducting generators. A recent discussion at the IEE [3] has shown that there is now an increasing awareness of the importance of back-of-core leakage fields; at least in very large machines.

It was while considering the back-of-core leakage flux in large machines, that the authors began to wonder whether smaller machines might not exhibit similar effects, if the ampere conductor loading of the stator were to be sufficiently high and the stator core sufficiently saturated.

They found that there was an appreciable back-of-core leakage flux present under transient conditions in a micro-alternator under short-circuit conditions and thereby satisfied themselves that the phenomenon was not inherently confined to large machines. They then turned their attention to other small machines to see if they too were similarly affected. Much to their surprise, they found that a standard portable electric drill demonstrated the transient back-of-core leakage phenomenon to a remarkable degree; attracting to itself under starting conditions a piece of thin sheet steel from a distance of about 20 mm.

Once the starting current had died away, the force disappeared. In an alternative version of the experiment, it was found that the magnetic field was sufficiently strong to operate a reed relay 100 times a second, and so to activate a light-emitting diode. This contribution records the results of a more systematic follow-up to the initial experiment

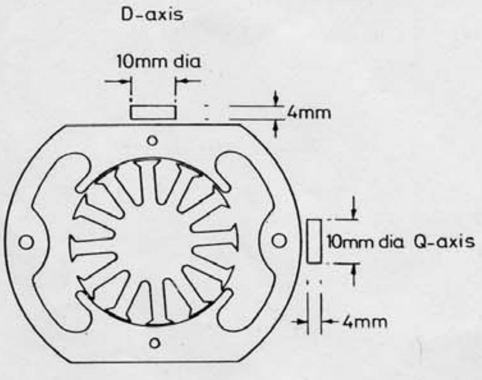

Fig. 1 *Magnetic circuit*

2 Experiments with a small universal motor

Because the magnetic circuit of the electric drill was not accessible, the experiment was repeated on a small universal motor with the magnetic circuit shown in Fig. 1. The no-load RMS current was 0.220 A and the number of turns per pole in the field winding was 467. A search coil and integrator were used to obtain traces of the flux density waves which were stored on a digital transient recorder.

Fig. 2 shows the *D*- and *Q*-axis radial flux density on startup. Initially, the *D*-axis radial flux density rises to a peak of 35 mT and then slowly falls to a steady state peak value of 5 mT. The *Q*-axis flux density is much smaller and never rises above a peak of 14 mT. The saturation effects are much more marked in the first few cycles than they are in the steady state.

Fig. 3 shows that the *D*-axis flux density and motor-current

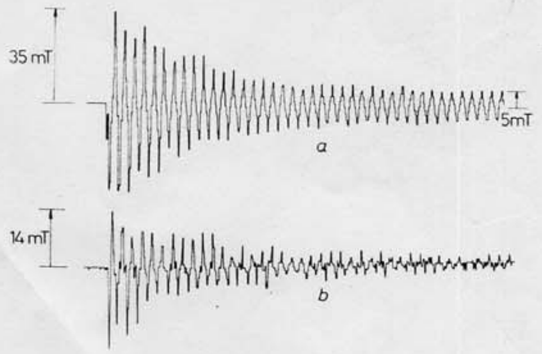

Fig. 2 *D- and Q-axis radial leakage flux on startup*

a *D*-axis
b *Q*-axis

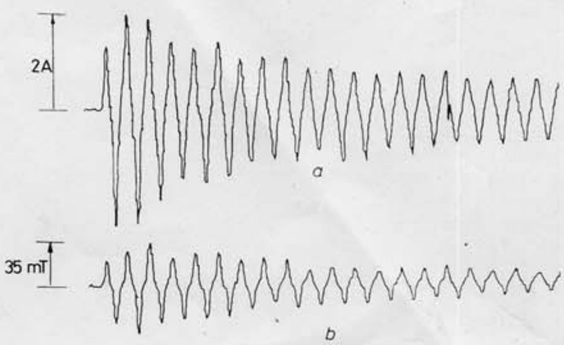

Fig. 3 *Correlation between armature current and D-axis leakage flux*

a Armature current
b *D*- flux

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waveforms were very similar, with somewhat greater peaking in the former – an effect probably caused by saturation.

Fig. 4 shows that when an iron surface is placed close to the search coil at the back-of-core (approximately 5 mm from the back-of-core), the local flux density more than trebles to a peak of 115 mT.

Fig. 5 shows *D*-axis flux densities for the drill machine. In Fig. 5*a*, for normal fullwave supply, the peak leakage flux density is about twice that observed for the universal motor of Fig. 1; possibly a result of the difference in rating. In Fig. 5*b*, with the drill motor operated with a series diode for speed reduction, the peak leakage flux density is slightly greater than for full wave, suggesting that the operating mode has a measurable effect on the leakage-flux magnitude. Table 1 summarises the results.

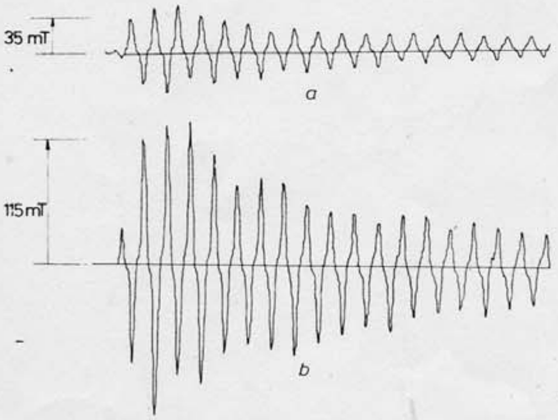

Fig. 4 *Comparison of D-axis radial flux at starting*

a Without iron surface nearby
b With iron surface nearby

3 Conclusions

A substantial leakage flux has been shown to arise at the back-of-core of small universal motors during starting, which is sufficient to produce an appreciable mechanical force on magnetic material placed near the back-of-core. The phenomenon is attributed to the excess field ampere turns which arise at starting, prior to the buildup of a back EMF, which saturate the core and force flux into the back-of-core region. The magnitude of the radial leakage flux is greatest on the *D*-axis and is approximately 25% higher at the ends than at the middle; as might be expected because of the end-winding contribution.

Placing iron in close proximity to the search coil raised the *D*-axis leakage flux density locally by a factor of 3; indicating that the presence or absence of iron in the back-of-core region plays an important part in determining the levels of leakage flux under transient conditions.

To some extent, the small universal motor is a special case, since it has a poor stator magnetic circuit and a high level of saturation. Nevertheless, there is no particular reason to suppose that the phenomenon will be totally confined to one particular type and size of machine. Larger machines may, for instance have a better magnetic circuit, but equally they tend to have higher electric loadings and, in the end regions at least, there will be large unbalanced magnetising ampere turns which would be able to contribute to the back-of-core leakage flux under the right circumstances.

Table 1: Peak back-of-core radial flux densities, mT

	M	*I*	*E*
Universal motor			
D-axis: at starting (2.0 A peak)	35	115	44
run (0.22 A RMS)	5	11	9
Q-axis: at starting	14		
Drill motor			
D-axis: at starting (fullwave)	75	–	–
at starting (halfwave)	84	–	–

M, at axial centre of core periphery
I, as *M* but with iron surface above search coil
E, at end of core

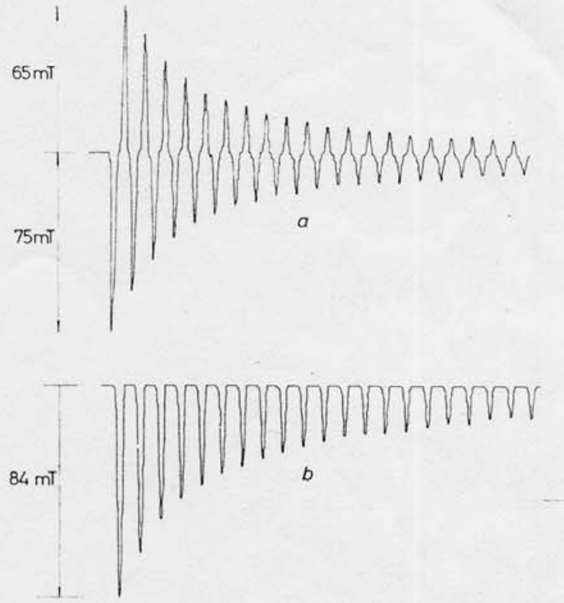

Fig. 5 *Effect of halfwave rectification on D-axis leakage flux in an electric drill on startup*

a Fullwave
b Halfwave

The experiment shows that the transient leakage flux is of sufficient magnitude in small universal machines to possess a possible nuisance value. It also demonstrates that, in principle, overload protection may be provided with either a search coil or reed relay placed in close proximity to the core without the need for any direct connection to the electrical circuit of the machine.

4 Acknowledgment

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5 References

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